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Low-Temperature Strengths of Metal Adhesives

THE National Bureau of Standards Boulder (Colo.) Laboratories recently investigated the low-temperature characteristics of four types of structural adhesives for the Wright Air Development Center. Tensile tests were conducted at temperatures ranging down to $-424°$ F with a filled epoxide, 3 rubber-phenolic, 4 vinyl-phenolic, and 2 epoxy-phenolic compounds. The epoxy-phenolics, both having a fiber glass supporting film, gave the best performance. The epoxide exhibited slightly less low-temperature strength, but faulty bonding apparently contributed to this behavior.

Structural adhesives for metals, first developed about 15 years ago, are expected to play an important part in the construction of future missiles and rockets that will be required to withstand a wide range of environmental conditions. These materials, having properties such as resilience, resistance to galvanic corrosion, and high strength-to-weight ratios, are particularly suitable for the assembly of the metal components used in space vehicles. In order to develop quantitative data on the low-temperature strengths of the various adhesive types now available for structural purposes, the present work was undertaken by William M. Frost of the Bureau's Cryogenic Engineering Laboratory.

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DETROIT

The metal specimens, furnished by a commercial laboratory, were of the standard lap-shear type with a 0.5-in. overlap length. Ten lap-joint panels were fabricated by overlapping and bonding sheets of clad 2024T–3 aluminum alloy and of 301 stainless steel. The epoxy-phenolic resins were applied to the stainless steel sheets, and the other adhesives bonded the aluminum sheets. After curing, the panels were cut into 1.0 by 7.5 in. strips, and 6 strips from each panel were sent to the Bureau for testing.

In the tests, the specimens were gripped 2.0 in. from each edge of the lap joint and stressed at a rate of 1,300 psi/min until failure. In all cases, the bonded area was held at test temperature for at least 10 min before load was applied with a hydraulic tensile-testing machine. The specimens were cooled to test temperatures of $-107°$ F and $-323°$ F in an insulated container that received coolant flowing from a pressurized Dewar. Thermocouples attached at the ends of the adhesive bonds were used in conjunction with a recording potentiometer to obtain temperature-time charts. Cooling to $-424°$ F was accomplished in

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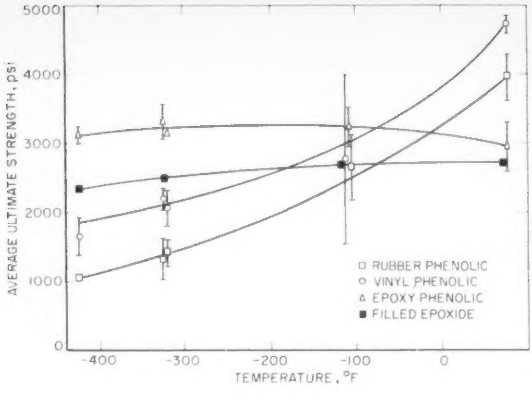
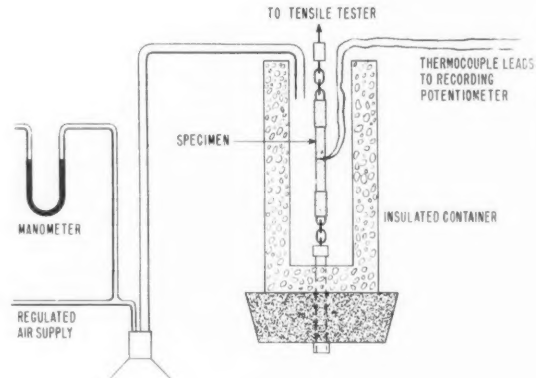


Left: **Test results show the tendency of adhesive metal bonds to decrease in strength as temperature is lowered. Only the epoxy-phenolics show a slight increase in bonding strength within the temperature range studied.** ***Below:*** **Apparatus used to cool adhesive-bonded metal specimens to temperatures as low as −424° F.**



two steps, precooling to −323° F with liquid nitrogen and final cooling with liquid hydrogen.

Failures were classified respectively as adhesive or cohesive, according to whether they occurred at the interface between adhesive and adherend, or strictly within the adhesive and supporting film. Failure of the rubber-phenolics was visually verified to be completely adhesive. At each test temperature the resin tended to part from the adherend in large flakes. The vinyl-phenolics also exhibited high percentages of adhesive failure. In one sample, only small scattered particles of resin clinging to the metal prevented the failure from being 100-percent adhesive.

Failure of the epoxy-phenolics was predominantly cohesive, with approximately 30 percent occurring within the thickness of the supporting glass fiber cloth. The remainder of the cohesive failure was in the rectangular spaces between strands where the resin parted from the cloth while still adhering to the metal. Adhesive failure appeared principally along the strands where pressure on the bond during cure had left a thin glue line. Upon examining these latter areas at high magnification, adhesive was found on the metal in etch pits and grain boundaries.

Discolored regions and pitted areas attested to the inferior bonding that was generally observed with the filled epoxy specimens. In some cases as little as 70 percent of the available area was effectively bonded. Failures appeared to be almost completely cohesive in areas where effective bonding was present, but these failures could not be classified accurately because of the discontinuous nature of the bond. Approximately 60 percent of the specimens failed near the center of the overlap length, leaving rectangular strips of adhesive 1.0 in. by 0.25 in. on each half of the specimen.

The average ultimate strengths of the four types of adhesives at −424° F were: rubber-phenolic, 1,065 psi; vinyl-phenolic, 1,650 psi; filled epoxide, 2,345 psi; epoxy-phenolic, 3,120 psi. None of these materials was formulated to withstand the particular test conditions to which it was subjected. Consequently, the results obtained do not indicate the utility of the various types for applications under normal environmental conditions.

1959 Bone Char Research Session

TO COMPARE and exchange data on sugar refining research and to inform the sugar industry on the progress of bone char research, the Sixth Technical Session on Bone Char Research[1] was held in Montreal, Canada, on October 19 and 20. Sponsored jointly by the National Bureau of Standards and the Bone Char Research Project, Inc., this session was highlighted by papers on ion-exchange applications and on the kilning of bone char for sugar refining. In all, 16 technical papers were presented. The Program Chairman of the session was Dr. V. R. Deitz of the Bureau.

Bone char, the product of pyrolysis of animal bones, is used almost exclusively in the sugar refining industry to adsorb the impurities present in raw sugar. Because of the enormous quantities of bone char required, the success of sugar purification depends largely on the efficiency with which the char can be regenerated for repeated use. In an attempt to understand the fundamental nature of bone char and other solid adsorbents, a research program was initiated at the Bureau. To date, there are 29 industrial supporters of this program, including cane sugar refiners and manufacturers of refining adsorbents in Australia, Belgium, Brazil, Canada, Cuba, England, France, Holland, Scotland, South Africa, and the United States.

The Technical Session opened with a welcoming address by E. J. Grant, who was in charge of local arrangements. Several aspects of commercial ion-exchange processes were then discussed. H. M. Rootare, Bone Char Research Associate at the Bureau, reported that bone char itself may act as an ion exchanger because of its ability to remove ash and anionic colorant from sugar liquors.

This possibility was amplified by Dr. R. Kunin of Rohm and Haas Company. Expanding on ion exchange were papers on a special ion-exchange process for controlling iron in sugar products by W. W. Blankenbach of the British Columbia Sugar Refining Company, on the use of highly basic resins in sugar refining by C. D. Conklin of the American Molasses Company, and on the determination of total anions in sugar liquors by M. D. Peiperl, Bone Char Research Associate at the Bureau. By using an ion exchange column to substitute chlorides for all other anions and then determining the new chloride composition on a commercial chloride titrator, it is possible to evaluate rapidly the total anion content. This gives the quantity of total anion nonsugar impurity which escaped bone char adsorption, and, properly evaluated, is an indication of the efficiency of bone char regeneration.

Kilning is an essential step in the successful regeneration of bone char and the key to its continued economic success. However, the chemical reactions involved are quite complex; they are being studied in detail by the Bureau. Dr. F. G. Carpenter, Bone Char Research Associate at the Bureau, discussed current progress in this field. The effects of temperature and kiln atmosphere on the chemical reactions in the kilning of bone char and the subsequent influence on "color" and "ash" removal of bone char treated under these controlled conditions are being studied.

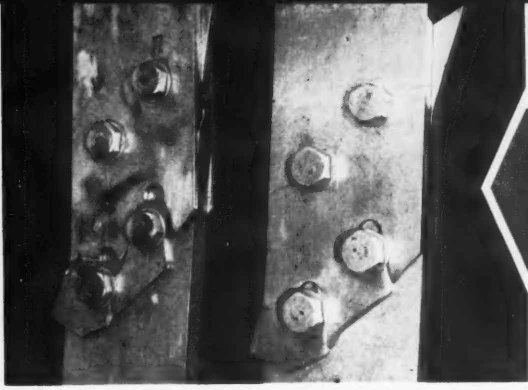
J. Durroux, M. Reboul, and J. Guerin of the Sucreries et Raffinerie Bouchon in Nassandres, France, described an improved kiln modeled after the old type pipe kiln. In comparison studies made of the different kilns used to date, it was found that more knowledge of the fundamental kilning reaction is necessary before radical changes can be incorporated in kiln design.

The determination and the significance of the nonsugar constituents in sugar liquors were discussed by L. F. Martin of the Department of Agriculture. Radioactive tracers are being used to explore sugar decomposition reactions and products. All of the impurities—compounds other than sucrose and invert sugar—aid in limiting crystallization of raw sugar, even when present in minute quantities. As most of these compounds do occur in raw sugar, they must be eliminated in the refining process. Dr. Pieter Honig added that the efficiency of different systems of purification can be best judged on the basis of the removal of these nonsugars.

Analytical methods suitable for the determination of these constituents have been and are being developed by the Bureau. Some of these methods have been applied to plant-scale char-cisterns, reported L. Washington of the American Sugar Refining Company.

The basic calcium phosphate system in bone char has certain properties which are found in soil constituents, fertilizers, and bone and teeth structures. The common feature of the surface chemistry of these materials was presented by Dr. S. R. Olsen, Department of Agriculture. His paper treated the nature and surface properties of freshly precipitated basic calcium phosphate. As the phosphates in soil and bone chars all have the property of high surface areas, studies of calcium phosphates in soil may shed some light on the problems encountered in the use of bone char in refining sugar liquors. E. D. Gillette, Refined Syrups and Sugars, Inc., and R. S. Patterson, California and Hawaiian Sugar Refining Corporation, added a further application: phosphate defecation (purification) and clarification of sugar liquors.

[1] *The Proceedings of the Session will be published in the near future.*



Designing Joints for High-Temperature Creep Conditions

Creep-rupture failures of large bolted joints of forged aluminum alloy at 400° F. *Left:* A brittle failure of 2014–T6 alloy. *Right:* A ductile failure of 7075–T6 alloy.

THE National Bureau of Standards, under the sponsorship of the National Aeronautics and Space Administration and the Navy Bureau of Aeronautics, is conducting a continuing program of research on creep and creep rupture in engineering structures. The work, which has included extensive tests of built-up structures, was undertaken to provide information on the strength and deformation of aircraft structures subjected to various load and temperature conditions. By increasing the understanding of creep behavior, this program has made it possible to design structures which can be used in creep-producing environments with a minimum of mechanical testing.

Creep is a continuing deformation under stress, characteristic of all metals at sufficiently high temperatures. For structural metals, it usually becomes significant at temperatures several hundred degrees F above room temperature, and at still higher temperatures it so weakens these materials that they become useless for engineering purposes. Between these limits, creep is a very important consideration in design.

Although considerable experimental work had been done to determine creep behavior in materials themselves, little was known until recent years about the effects of creep on built-up structures. As a first step toward evaluating the creep behavior of structures, the present series of investigations was undertaken by L. Mordfin, N. Halsey, and others of the engineering mechanics laboratory. These studies, which began in 1952 with the most elementary built-up structure—the joint, have since been expanded to include more complex structures.

Before the Bureau's work, the design of joints for weight-sensitive structures required a certain amount of trial-and-error testing under the load and temperature conditions which would be imposed in use. With the methods below, it is now possible to calculate approximate designs and thereby reduce the amount of testing required.

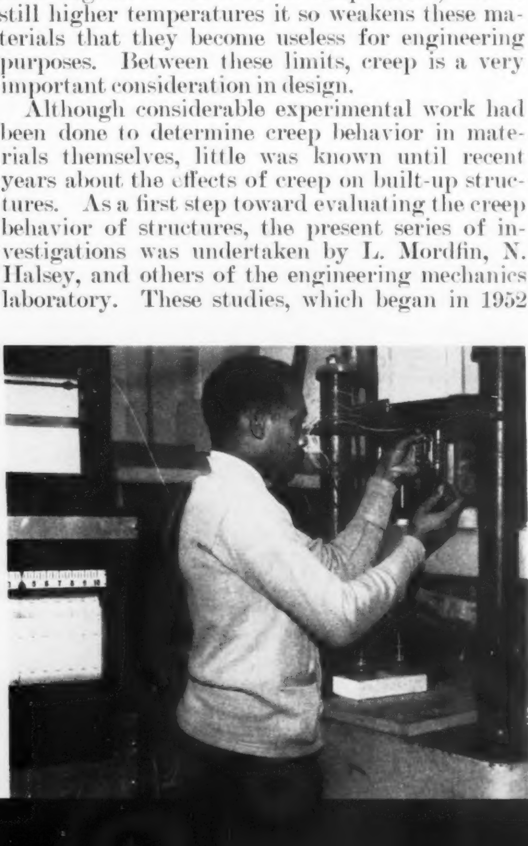
Creep Rupture of Joints

To calculate the creep rupture strength of joints, the Bureau recommends a method similar to the calculation of strength under static conditions, but with the addition of the variables time and temperature.

Under static conditions, the strength of a joint is normally calculated from the ultimate tensile, shear, and bearing strengths of the materials involved. The loads required to produce each of the several modes of failure are compared, and the strength of the joint is taken to be the smallest of these.

In creep loading, just as in loading at room temperature, a riveted joint may fail by tension, bearing, or shearing. However, creep rupture strength decreases both with temperature and with the length of time that the joint is at a given temperature. Specification of these variables allows the loads that will produce each of the various modes of failure to be calculated.[1]

Very often, creep rupture strengths of the materials are known for tension loadings only. The creep rupture properties may then be estimated in terms of the efficiency—the ratio of the strength of the joint to the strength of an unriveted sheet of the same material. The assumption that this ratio is the same under creep conditions as under normal static conditions implies that the variation of the bearing and shear strengths with temperature and time is similar to the variation of the



Creep testing of joints. The specimen under load is in a furnace (upper right) maintained at creep-producing temperatures. The differential transformer, being mounted by N. Halsey on the extensometer rods below the furnace, transmits the time-dependent deformation to the recording equipment at upper left.

tensile strength. The creep rupture strength of a joint is therefore the tensile creep rupture strength of the sheet material multiplied by the joint efficiency.[2]

Creep Deformation of Joints

For many structures, such as airplane wings, joints which do not rupture within the specified lifetime are not sufficient. In order not to destroy aerodynamic contours, the joints must be strong enough to prevent excessive deformation.

Designing for this allowable deformation is facilitated by the stress-sensitive nature of creep; relatively large changes in rate of deformation result from small changes in stress. Thus, the creep deformations due to the individual stresses—tensile, bearing, and shear—often differ by as much as an order of magnitude in a given joint. Hence, the deformation, or elongation, of a joint can usually be attributed to the stress producing the largest deformation—the stress which eventually would produce rupture. For example, a joint which is calculated to rupture under bearing may be considered to creep in only that one type of loading. The elongation is, then, the same as that for a bearing specimen subjected to the same stress and temperature.

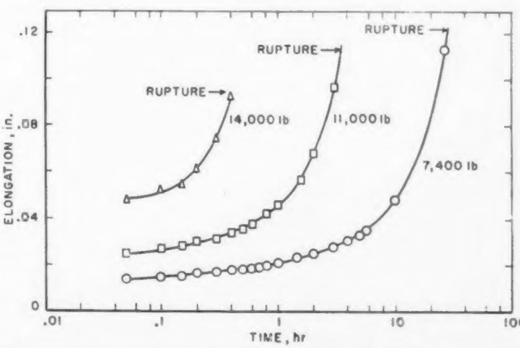
Effects of Varying Loads and Temperatures

In many applications, joints are subjected to conditions of varying loads and temperatures, where calculations of the time to rupture or the time to reach the specified allowable deformation are desirable.

For this purpose, the history of the joint is divided into small increments of time during which load and temperature may be considered constant. The fraction of life expended during each increment is, then, that increment divided by the total expected life under the constant load and temperature. When the creep behavior in any increment is not affected by the conditions in previous increments, rupture or the specified allowable deformation is reached when the summation of the life fractions reaches unity.

Such behavior, however, is obtained only when the material is metallurgically stable and when the load and temperature variations are not severe. In the general case, creep is a function of past history, so that the limiting condition is reached when the summation of the life fractions equals some quantity other than unity. This quantity is called the time ratio.

The most desirable means of estimating the time ratio for a joint is to base it on the behavior of the material of the joint. That is, the time ratio for a joint may be considered equal to the time ratio for rupture of the material of the joint under identical conditions.[3]



Representative creep curves obtained at 800° F for three riveted joints of titanium alloy. The tensile loads of 14,000, 11,000, and 7,400 lb. were maintained constant throughout the tests, which ended at rupture. Equivalent curves may be predicted directly from materials data, reducing the amount of mechanical testing required.

Effects of Prior Creep

A material specimen that has undergone a certain amount of creep would ordinarily be expected to yield more rapidly to momentary periods of overload than would a "new" specimen. It has been found, however, that moderate amounts of prior creep produce a change in tensile properties which is usually small and sometimes beneficial. Similar behavior has been observed for riveted joints. In fact, for design purposes, it is generally satisfactory to consider that the reduction in strength of a joint due to prior creep is equal, percentagewise, to the reduction observed for the material from which the joint is fabricated.

Accuracy of Calculations

The methods that have been described make it possible to design riveted joints for creep conditions, without testing the joint. However, the dependability of the design can be no better than the materials data upon which it is based. Check testing of finished designs is therefore recommended when possible.

The strength of a joint that is required to have a specified lifetime under given temperature conditions can be determined within 10 percent. On the other hand, in calculations of the lifetime for a given load and temperature condition, inaccuracies may be as high as 2 to 1—a result of the stress-sensitive nature of creep, whereby small variations in stress lead to large variations in lifetime.

[1] For further technical details, see Creep behavior of structural joints of aircraft materials under constant loads and temperatures, *by L. Mordfin and A. C. Legate, NACA Tech. Note 3842 (1957).*

[2] Creep and static strengths of large bolted joints of forged aluminum alloys under various temperature conditions, *by L. Mordfin, G. E. Greene, N. Halsey, R. H Harwell, Jr., and R. L. Bloss, Inst. Aero. Sci. Preprint No. 779 (1958).*

[3] Investigations of the creep behavior of structural joints under cyclic loads and temperatures, *by L. Mordfin, N. Halsey and G. E. Greene, NASA Tech. Note D–181 (1959).*

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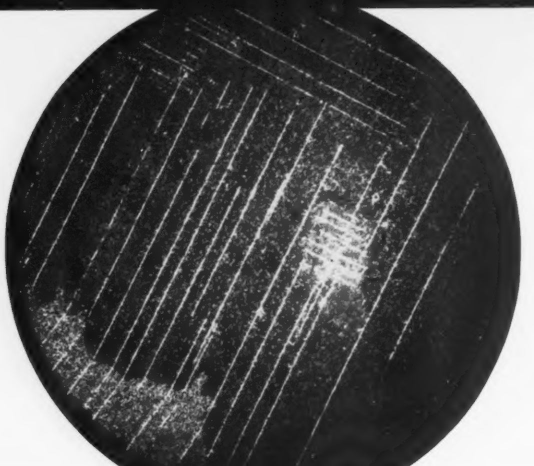

Surface of an aluminum alloy specimen subjected to reversed torsional loads. The direction of the slip bands (white lines) is different in each grain, even in the small grain near the center which is completely surrounded by a grain of a different orientation. (×32)

TODAY, metals are more important to scientific and engineering progress than at any time in history. They have become irreplaceable construction materials of a modern civilization. Mechanical properties such as strength and stiffness permit them to be machined, welded, rolled, pressed, drawn, or bent into any desired form. Because of their resilience and toughness, they yield without fracture to shock and vibration. These and similar qualities have achieved for metals a foremost place in the ranks of industrially useful materials. Nevertheless, if metals are to keep pace with contemporary and future technological advances, a better understanding is needed of metallurgical structure, and of the influences of heat treatment and of temperature extremes on this structure.

To provide data that will assist in meeting this need, the Bureau has accelerated its program of fundamental research on the mechanical properties of metals. Instabilities in alloys, changes within the space lattice at the atomic level, surface reactions, the creep process, metal fatigue, all of the factors controlling the response of metals to external forces, are being investigated in this effort. It is hoped that from information derived experimentally, practical methods will be devised for improving the performance of metals, and for developing new alloys as they are required by scientists and engineers. To this end, the work on mechanical properties of metals is closely coordinated with concurrent Bureau programs in metal physics, chemical metallurgy, and corrosion.

Metallurgical Structure

Metal fatigue is the most common cause of mechanical failures in service. This phenomenon may occur in any component or machine part subjected to fluctuating or repeated stresses, sometimes even after many millions of cycles of stress. Hence, much consideration is given to engineering design to increase the useful life of metal parts; for instance, in the aircraft industry where the effects of vibrations and other sources of repeated stress must be taken into account. However, in order to achieve optimum design, engineers must be able to predict the behavior of stressed components with a high degree of accuracy, and this ability requires an understanding of the relation between the structure of metals and the fatigue process.

It is well known that fatigue cracks generally start on pre-existing slip bands within the grains of a metal. However, to study the conditions under which cracks start in commercial metals is difficult, principally because these metals are composed of a large number of infinitely small grains. The Bureau has therefore produced aluminum specimens with grains 2 to 3 mm in diameter, so that the behavior of individual stressed grains could be observed more readily.

In one study with these specimens, individual grains were found to act independently of their neighbors. There was no evidence that grain boundaries or interaction with neighboring grains promote cracking. It appeared that the principal factor to be considered in the fatigue-crack initiation of polycrystalline aluminum is the resolved shear stress on the plane of easy slip in the slip direction [1].[1] This study was sponsored by the National Advisory Committee for Aeronautics, now the National Aeronautical and Space Administration.

Results of another study sponsored by this agency showed that the preponderance of fatigue cracks starting at the edges of a metal specimen is caused by the stress pattern, rather than by lower fatigue strength at the edges [2]. In its work on metal fatigue, the Bureau has made a study of the factors that influence the fatigue strength of spring wire. The results of this work, which has been carried on under the auspices of the Army Ordnance Corps, should be of value in efforts to improve the performance and reliability of the springs used in ordnance devices [3].

Chemical reactions at the metal surface are known to have an important influence on fatigue behavior. It has recently been observed that if transparent tape is applied to the surface of a

[1] Figures in brackets indicate literature references at the end of this article.

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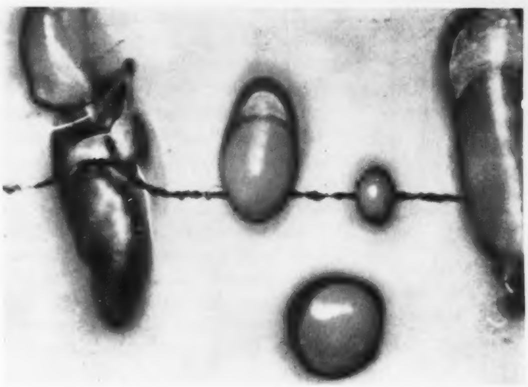
fatigue specimen, bubbles form under the tape at about the same time that fatigue cracks are initiated. These bubbles, caused by gas liberated as a result of surface reactions, are expected to provide a useful means for studying such reactions [4].

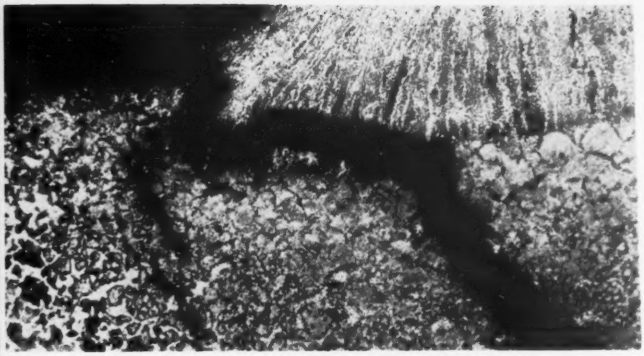
For several years, X-ray diffraction techniques have been used at the Bureau to determine stresses that occur within a metal's structure. With these techniques, the lattice strain can be ascertained by measuring changes in interatomic spacing. Because of its selectivity and directionality, X-ray diffraction has advantages over other means for evaluating stresses.

In a recent study with iron specimens in which these techniques were used, it was found that plastic deformation of this metal causes residual stresses to develop on a microscopic scale [5]. An investigation of the elastic and plastic behavior of the ferrite lattice in a low-alloy steel showed that the stresses observed by X-ray diffraction exist in a relatively undistorted crystalline material. These stresses were balanced by oppositely directed stresses, either in distorted portions of the crystals adjacent to grain boundaries or in slip bands [6].



Above: **Ruth E. Dowden observes a torsional fatigue test on a small flat specimen. A piece of transparent tape covers the surface of the specimen.** ***Left:*** **Gas bubbles appearing under the tape during the test are indicative of the surface chemical reactions involved. (×466)**

Left: **Mounting a specimen for electron microscopy.** ***Above:*** **H. C. Vacher adjusts an electron microscope as he views the image on a fluorescent screen.**



Section of a steel bar from one of the locks on the St. Lawrence Seaway showing origin of a fracture. This bar, one of two holding the lock gate in position, cracked because of a stress that developed from dimensional changes during cold weather. Studies showed that the steel at the most highly stressed point had been embrittled by the heating effect of a heavy weld. Brittle steel adjacent to the toe of the weld (upper right) is easily distinguished from the normal structure of the metal (lower left). (×30)

In two-phase alloys the thermal expansion coefficients of the two phases usually differ. Consequently, there is a tendency toward unequal changes in the volume of each phase as the metal cools from the liquid state. The unequal volume changes cause intergranular forces to arise which are known as textural stresses. These stresses are to be distinguished from the other kind of internal stresses occurring in metals known as body stresses [7].

In Bureau experiments it was possible to measure these textural stresses by X-ray diffraction. Results indicated that a completely stress-free condition cannot be obtained in metals that have more than one phase. Textural stresses must therefore be considered in investigations to determine the causes of corrosion, metal fatigue, and crack formations in metals used for industrial purposes [8].

Effects of High and Low Temperatures

The changes that metals undergo at high temperatures are becoming more and more important to the development of rocket machinery and astronautical devices. To a somewhat lesser degree, the effects of very low temperatures on the mechanisms of deformation and fracture of metals are of concern. As new test methods are devised, investigations of high-purity metals and the newer alloys are proceeding under both types of environmental conditions.

Titanium and its alloys, because of their high strength-to-density ratios and high resistance to corrosion, are promising materials for many cryogenic applications and for certain aircraft and missile components. Since 1952 the Bureau has been studying the mechanical and thermal properties of this comparatively new metal, as a part of its comprehensive program on the deformation of metals. In early studies for the Army Ordnance Corps the effects of temperature were correlated with the tensile and impact properties and the true-stress—true-strain relations for an annealed commercially pure titanium [9].

It is necessary to know how titanium and its alloys react at low temperatures under both uniaxial and multiaxial tensions in order to understand their rheological behavior. Several investigations were therefore conducted at temperatures down to −196° C to evaluate the combined influence of prior strain-temperature history and notch geometry on the tensile behavior of commercially pure titanium and a titanium alloy containing aluminum and manganese. Notch geometry is significant because brittle failures at low temperatures are often associated with the presence of a notch, either as a design feature or as a defect. Measurements of strength and ductility characteristics disclosed that strength indices—that is, resistance to flow, notch strength, true stress at maximum load, and fracture stress—are generally increased, and tensile ductility is decreased, by increasing the notch depth or by lowering the test temperature. Analysis of the data indicate that these metals are very notch sensitive, particularly at low temperatures. The decrease in ductility with increase in depth and sharpness of notch is attributed not only to the initial stress concentration and accompanying severe strain hardening of the metal at the root of the notch, but also to the triaxial stress system induced by the notch. In general, the embrittling effect associated with the stress concentration was somewhat greater than that caused by triaxiality of the stress system. The results emphasize the importance of taking special care to eliminate notches. If they are unavoidable, their embrittling effect should be minimized by designing notches with the largest possible root radius [10].

It is fairly well accepted that the rate-determining factor during creep of metals is the motion of defects through the crystal lattice by thermal activation under applied stress. However, of the numerous equations proposed to describe this behavior, none has been found completely satisfactory. To provide basic information that will assist in forming a theory to explain the structural changes that occur during creep, the Bureau has been conducting a long-range program. In the most recent study, tests were made at temperatures up to 1,200° F. The influence of stress, strain rate, and prior strain history on the mechanism of creep, and on the flow and fracture characteristics of high-purity nickel and copper and their alloys was determined.

The results conform closely to the concept of generation and exhaustion of lattice defects during the first stage of creep, as well as to the parabolic strain-time law over limited ranges of stress and strain during the second stage. It was found

that the resistance to creep is materially increased by alloying the component metals and also by cold-drawing, provided the creep temperature is below the recrystallization temperature range. The increase in creep resistance by cold-drawing is accompanied by a corresponding decrease in ductility, which is also affected by temperature and strain rate [11].

Among studies presently under way is one using electron microscopy and diffraction to determine the mechanism of hardening of the precipitation-hardening stainless steels, and to establish the relationships between heat-treating variables and the microstructure of metals. These techniques are also being used to investigate the mechanism and kinetics of phase transformations, and the structure of metal oxide films.

High-Strength Steels

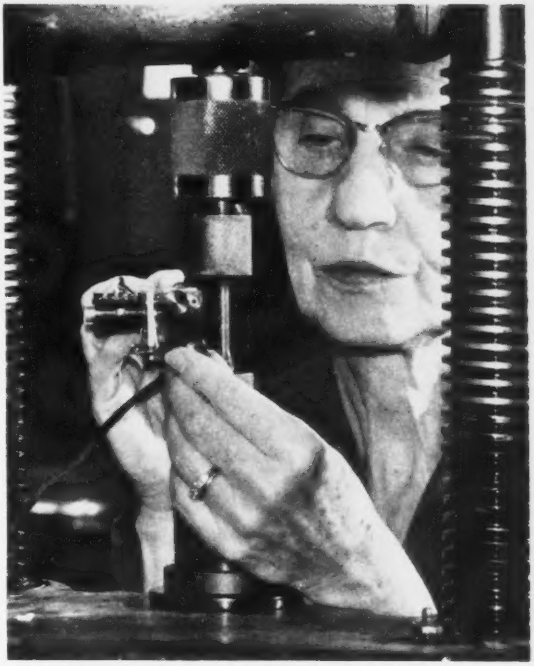
The fatigue strength of most ferrous metals is roughly proportional to the tensile strength. But when steels are heat-treated to high hardness, this proportionality disappears, and with increases in tensile strength to above 200,000 psi, there is little improvement in fatigue strength. In an effort to resolve some of the conflicting views concerning the influence of a number of metallurgical variables on this behavior, the Bureau recently conducted experiments on several high-strength steels [12].

The study disclosed that retained austenite lowers fatigue strength. Austenite is the face-centered cubic form of iron that exists in steel at high temperatures. Under stress, retained austenite is transformed to untempered martensite, which probably accounts for the deleterious effect. With suitable heat treatment, however, retained austenite can be eliminated in most carbon and low-alloy steels. The results of this research are expected to have practical applications in the choice of industrial steels.

The Bureau's thermal metallurgy laboratory has recently been engaged in developing an ultra high-strength steel for the Navy Bureau of Aeronautics. By modifying Type 4340 steel an alloy was found that had high hardenability, sufficient ductility for use as structural members in aircraft, and a tensile strength up to 300,000 psi. Although these properties were obtained in laboratory induction furnace heats, melted without slag, they may be duplicated or even improved upon in commercial practice [13].

Mechanical Failure of Metals

For many years the Bureau has examined metal parts that have failed in service to obtain evidence bearing on the causes of failure. These examinations have been undertaken for other government agencies such as the Ship Structure Committee of the National Research Council, the Civil Aeronautics Board, and the Defense Department.



A highly sensitive extensometer used to measure and record the behavior of a cylindrical steel specimen under tension. Mrs. Carolyn R. Irish alines the instrument for attachment to the specimen.

From 1942 to 1953 an extensive study was made of steel plates from more than 100 merchant vessels that had fractured while in use. The results of this work showed that the performance of a steel in service can be correlated with the mechanical properties as measured in the laboratory. The information thus derived has provided much of the basis for the current specifications for ship plate [14].

Investigations for the Civil Aeronautics Board and defense agencies have often had a bearing on decisions regarding the safety of transport aircraft, particularly with regard to correcting conditions that have led to accidents. Laboratory work includes examination of the failed parts by visual, microscopic, and metallographic methods, as well as mechanical and chemical tests. Data have been compiled on the circumstances of the failure, together with factors indicating errors in design, in material selection, and in fabrication [15].

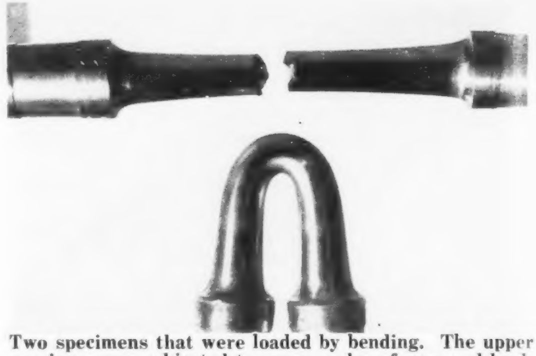
Gage Block Stability

For a number of industrial processes as, for example, in the making of machine tools, ball bearings, and missile guidance mechanisms, test gages for dimensional control must be very precise; and the gage blocks used in checking the accuracy of these gages must be even more accurate. At pres-

ent the Bureau regularly calibrates master gage blocks to an accuracy of 1 part in 1 million, that is, to the nearest millionth of an inch for inch-long blocks, and a goal has been set to increase this accuracy by a factor of ten. As part of this program, partially supported by several industrial firms,[2] extremely stable materials are being sought for gage block construction, so that measured lengths will not change appreciably with time.

From recent experiments, nitrided 410 stainless steel appears to be a promising material for ultraprecise gage blocks. Specimens were found to be corrosion-resistant to atmospheric conditions. Moreover, the gaging surfaces are extremely hard and wear-resistant, and can be finished to a high degree of smoothness, flatness, and parallelism. Measurements thus far indicate that these specimens have the required dimensional stability. However, evaluations will continue for an extended period, since previous observations of commercial blocks have shown that the results of measurement over a year or two are not necessarily indicative of future behavior.

Looking ahead to the metallurgical requirements of a space age, the Bureau expects to place increasing emphasis on the study of all aspects of atomic structure that influence the behavior of metals in service. At present, techniques are being developed to obtain basic data that may point the way to new uses for metals. Ultimately this work may lead to new alloys that will withstand the most rigorous of environmental and physical conditions.



Two specimens that were loaded by bending. The upper specimen was subjected to many cycles of reversed loading and failed with a typical fatigue fracture, showing no ductility. A single high load was applied to the lower specimen.

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